Guidance and Control Systems FAQ (Frequently Asked Questions)

May 7, 1996

[Note: This originated as part of the rec.models.rockets FAQ that was maintained by Jack Hagerty (jack@rml.com). Since I hate for **any** information to be lost, here's the last updated version before it was deleted from the rmr FAQ.]

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1. What kinds of Guidance Systems have been tried? Does anything work besides fins?
2. All this talk about reference platforms seems so complicated. Why not get some of the gyros the RC-Helicopter folks use? These are small, relatively cheap, and are designed to hook into servos.
3. What are some of the sources for stabilization equipment?
4. What can you tell me about control systems for rockets?
5. What are some sources for electronic control systems and components?
6. I keep launching my rockets completely out of sight! Are there any kinds of Recovery Aids to get them back?

Updates

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January '96:  Reformatted to better match new FAQ format; no new data.
November '94: Added "Recovery Aids" section.
August '94:   Added "John Sicker" to "Sources" section.
June '94:     Added "Designex" and "muRata" to "Sources" section.
April '94:    Split off from "Payloads" section and renumbered Part 6.
              Added "Pendulum" discussion and sources of components.
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Introduction

The only universally accepted method of model/HPR guidance is the static fin. While these take on an enormous variation in shape, size and location, they all do the same thing: move the CP back behind the CG so that the rocket is statically stable. Since the beginning of the hobby, folks have been experimenting with more sophisticated ways of guiding their rockets for lots of different reasons. None of the systems have been so successful that the technique has been incorporated into a "regular" rocket, except to further the experiments.

Compared to other parts of this FAQ, the following will seem much more theoretical than practical. This is necessary because a flying rocket is an extremely dynamic system and controlling it with an active guidance system is a very non-trivial task. Before you jump in and start grafting gyros and servos to something that can approach the speed of sound you have to understand the basics behind how such things work...or, more importantly, don't work. After the theoretical grounding, specific examples and references will be given so you can review the work of others.

After the Guidance Systems is a section on Control Systems. While they sound similar, Control is much simpler in a rocketry context. This section will deal with the sequence controllers, timers and other increasingly sophisticated means of making sure that the rockets (especially the big HPR stuff) perform as desired.

Finishing up this part of the FAQ is a new section on yet another niche for electronics in the hobby: Recovery Aids.

14.1 What kinds of Guidance Systems have been tried? Does anything work besides fins?

Guidance, Active vs Passive

All hobby rockets, with the exception of the experimental ones described later, are passively stable. They achieve this by the simple expedient of placing the CP behind the CG, which is almost always done with fins. Passive fins are placed at the back of a rocket because that's where they are needed to provide negative feedback. As much as this sounds bad to the touchie-feelie crowd, negative feedback is simply an engineering term which means that any disturbing forces are fed back into the system in the opposite direction. Thus any force which causes, say, a positive pitch will make the fins generate a negative pitch force to help put it back right. Positive feedback, conversely, causes continued motion in the *same* direction, exemplified by the tight spirals of an unstable rocket where the fins push it further in the direction of the error.

I say that passive fins 'help' put it back right because, being a passive system, it has no way of knowing which way 'right' is. If you launch vertically with a side wind, then passive fins will steer the rocket to a direction which is a combination of the side wind and the apparent wind caused by the rocket's own motion (this is known as vector addition and will come up again further down). We all know this as 'weathercocking.'

Active fins are a whole 'nother story (we'll continue using fins in this discussion even though there are many different ways to affect a rocket's flight path as we will see later in the 'Gyro' section; fins are just the

most common). Active fins are usually pivoted on their root edge like the rudder on an airplane. The biggest debate on active fins is which end of the rocket to place them. Both front and rear have their trade-offs.

Rear Mounted Fins

Rear mounted fins seem more "right" because that's where we're expecting to see them. They also have a legitimate benefit in that should the guidance system fail, the fins will add to the static stability, just like always. One consequence of rear mounted fins to keep in mind is that the control inputs must be reversed. Just as an airplane rudder must push the tail left in order for the plane to turn right, rear mounted fins must turn in the direction of the error to correct the rocket's path. This leads to them being very effective since you get to add the fin's angle-of-attack (alpha) to the rocket's.

For example - If the rocket develops a 5 degree alpha with respect to the vertical, then the fins, since they're pivoted the same direction, will add another 5 degrees thus doubling the amount of corrective lift generated (assuming of course that the angles are small enough that the fin doesn't stall). The down side of this is that the fins might prove *too* effective and could cause the rocket to overshoot its desired path and head the other way. This could lead to an unstable oscillation if not damped out. One way to lessen their impact is to make the fins small, which has the usual benefits of less weight, less drag and (if this is a scale model of a finless missile) less visual impact.

Other problems with rear mounted fins is that the back end of a rocket is already a pretty crowded place. There's that massive heat generator (the motor) taking up most of the airframe, and the last thing you need is more mass from fin actuators, bellcranks, bearings, etc. at the "wrong" end detracting from the rocket's static stability.

Front Mounted Fins - For front mounted fins, one is tempted to say "take everything in the previous section and reverse it" :-) It's not quite that simple as they have their own subtleties. The visual response from seasoned rocket designers is usually a shudder since front fins are what everyone is always trying to avoid. Indeed, should the guidance system fail they will pull the CP forward enough to make the rocket statically unstable. For this reason, forward mounted fins are almost never used by themselves, but rather in conjunction with static rear-mounted fins to provide "trim."

Front mounted fins are not very effective; the reason being that when they're up front, the fins *subtract* their angle of attack from the rocket's. Think of it this way: While the rocket is ascending vertically, the fins are also vertical, of course. If a gust of wind induces, say, a positive pitch then the control system will command the fins to a negative pitch position. This puts the fins nearly vertical again with almost *no* angle of attack WRT the relative wind to generate corrective lift. It's not until the rocket starts developing some horizontal velocity (since the motor is no longer pointing completely vertically -- vector addition again) that the fins start generating some lift to put the rocket on course.

While this makes front mounted fins less desirable as a primary guidance solution, it actually enhances their use as guidance trim. By adding active forward mounted trim fins to a basically stable rocket (with passive rear fins) you can "fly it all over the sky." Since the fins are less effective, your steering inputs don't have to be so subtle and the risk of overshoot is greatly diminished. As speeds increase you really don't want a control system that's too "touchy." This is, in fact, why supersonic missiles like the Sidewinder and AMRAAM use exactly this control scheme.

Finally, front mounted fins can have all the benefits that rear mounted fins lack: system comptactness (since the control system, fins and actuators are all at the same end), static balance (all the system mass is at the front), avoiding the heat and space restrictions around the motor, ability to be recovered separately in their own payload compartment, etc.

Well, with that "ground school" out of the way, let's get on to some specific examples:

Historic - Ram Air.

The old **Model Rocketry Magazine** carried a two part article by Forrest Mims in the February and March 1970 issues on Ram Air guidance. In this system, air entering through a hole cut through the central axis of the nose cone was redirected out side ports by a rotating duct. The idea was that under normal flight, the air would "puff" out the four side ports (along the pitch and yaw axes) in rapid succession causing no more than a wobble in the flight path. When you wanted to change course, the duct would be quickly stopped in front of the appropriate side port to let air effect the change then it would go back to spinning. The problem (which should have been obvious, IMHO) is that a flying rocket is a classic free body and that the torque necessary to start and stop the spinning duct would cause the rocket itself to spin the opposite direction. This means that the port you were lining the duct up with was no longer aimed in the "right" direction. The system used a sun-seeking sensor which looked out the central ram air inlet.

An equally creative (and unworkable) guidance method by the same author was detailed in the Nov '70 **MRM**. This one started out the same with a central ram air inlet and a side port (but only one). Inside the side port was a pair of electrical contacts connected to an enormous capacitor. The air entering the top spun a small propeller connected to a screw. The screw closed the contacts discharging the capacitor and causing an acoustic wave to exit out the side port. The idea was that this acoustic wave could be used to influence the rocket's path. Of course, this setup was just used to see if any course change was detectable at all (it wasn't). How to recharge the capacitor and time/aim the discharges was left as a project for future generations :-) Gotta give this guy an "A" for lateral thinking!

Sun/Horizon (target) seeking

The Ram-Air system described above was a sun seeker, albeit a very crude one. The sun is a marvelous target for experimental guidance systems. It's massively bright, so it's easy to detect (in fact, it's hard to miss :-). It's always "up" in the sky [if you're not launching too close to sunrise or sunset] so you don't have to worry about violating the safety code WRT flight path angle. Finally, it's out at infinity, so you don't have to worry about actually reaching it (i.e. a constant target).

Perhaps the most in-depth sun guidance system yet built was done by the Zunofark team of George Gassaway, Matt Steele, et. al. and covered in mind numbing detail in the May/June and July/August 1992 issues of **HPRM**. The articles are a reprint of the research paper that took first place in the Senior division at NARAM 30 (this paper is also available from NARTS). It covers all phases of the project from basic theory and construction details through experiment design and execution. The research vehicle used the passive rear fins/forward trim fins control scheme. Control input was by a quadrature style sun sensor looking through either a transparent or translucent nosecone. Fin actuation by RC airplane type servos. The articles include appendicies.

Pendulum

An article of similar depth to the "Sun Seeker" above, but all theory, was presented in the July/August 1993 **HPRM**. Author David Ketchledge starts with the basics by revisiting the famous Barrowman Equations for determining the CP of a rocket. He then continues on to explore the dynamics of rocket flight. My only problem with the article is that the equations are presented in FORTRAN or BASIC style arithmetic statements rather than using standard mathematical notation which makes it difficult to follow. At the end of the article, Mr. Ketchledge proposes a guidance system design based on a free hanging pendulum to use as the vertical reference. He provides multiple computer simulations to show the effectiveness of this sensor compared to several others (including the Zunofark sensor described above).

Pendula are an interesting concept, and are often chosen by those designing their first active guidance system. Mostly this is due to being simpler and more intuitive than gyroscopes in their operation. However, even a simple analysis of operation in the "real" world (as opposed to a computer simulation) shows their deficiency as a primary guidance tool. The following essay by Jim Kerns (kerns@ed8200.ped.pto.ford.com) elaborates:

Pendulums don't react to gravity.

Pendulums react to any moment (torque, couple) that appears between the weight and the pivot. When a pendulum is stationary this moment would be created by the force of gravity on the weight and the reaction force from the ground applied through the pivot. Now, what happens in a rocket (or other free body)? When the system is in free fall, the mass is pulled down by the force of gravity so it is accelerating downwards at 1 gee. Also, the pivot (and attached rocket) is pulled/accelerating downwards at 1 gee. Net result? Nothing. The force due to gravity is equal to the force required to accelerate the masses (inertia) at 1 gee so there is no net moment acting between the pendulum and the pivot.

The pendulum would react to external forces (thrust, drag...) but even with these present, it will still not react to gravity. That is, pendulums react *only* to forces applied to the pivot that are not applied to the weight. A pendulum inside a free body will exactly align it self with the forces that are applied to that body but not to the weight.

Not convinced?

Think about what happens when someone lets go of a pencil in a spacecraft that is orbiting the earth - it doesn't appear to fall. Observing a space craft from "outside" it is very clear that it is falling quite rapidly. But from inside the space craft, that acceleration is not observable - things appear to be "weightless" - not affected by the forces of gravity. Likewise, a pendulum would not tend to point "down".

A pendulum in a rocket that is thrusting horizontally will not point at some angle between the horizontal thrust and "down", it will point exactly horizontally (and the rocket will fall towards the ground at 1 gee). It should be pointed out that a pendulum in a rocket that is moving truly horizontally (due to aerodynamic lift keeping it from falling) will point at some angle towards the ground. But, this is not because it is reacting to gravity, but rather because it is reacting to the force (lift) that is acting on the pivot but not the weight.

Bottom line: A pendulum inside a rocket in flight will give absolutely no indication of which direction is up.

Does this mean that I can't use a pendulum to create a guidance system?

Yes/no/maybe... It depends on what you mean by "a guidance system." From some of the criticisms of pendulums (pivot friction, small deflections relative to thrust, etc) some folks mean "something that makes a rocket fly straight up". If so, a pendulum clearly can't work. But, that must also mean: Fins Don't Work.

Well, it's true. Passive fins as found on 99% of all hobby rockets don't work. You can't use fins to be sure that a rocket will fly straight up. Why not? Well, as described previously under "Active vs. Passive," fins don't know which way up is. Plus they don't react to gravity. What they react to is a difference between the orientation of the rocket and the apparent wind. For example, when a rocket comes off the end of the launch rod a cross wind will tend to force the rocket away from its vertical path and make it point towards the wind. Also, they only react in proportion

to the magnitude of the angle between the rocket and the apparent wind (angle of attack). So, for example, if thrust is applied off center the fins will not completely correct for this and the rocket will tend to curve off in one direction.

Now, I probably didn't tell you anything you didn't already know about fins, right? So, why did I waste your time with the last paragraph? I wanted to be very clear what it is that we really need from a "guidance system." We don't need something that senses up. We don't need something that is particularly accurate. All we really need is something that tends to keep the rocket pointing in the general direction of the launch as long as the magnitude or duration of external disturbances or internal imbalances are not too large.

So, if we don't need a system that senses gravity and will not insure that a rocket goes "up" (e.g. fins)... perhaps we shouldn't be too quick to say we can't use a pendulum just because it can't sense which way is down or because there will be friction in the pivot.

So how can a Pendulum be used?

Now, given that a pendulum does not know which way is down, can we still get any useful information from one?

Let us consider a pendulum hung at the center of gravity of a rocket. What happens when it is hit by a crosswind (say, from the left)? As the rocket is accelerated to the right, the pendulum (as viewed from inside the rocket) would tend to move to the left. If it were attached to movable fins (or whatever) it could be made to cause the rocket to turn to the left, i.e. weathercock. When the acceleration stops or is offset by the rockets thrust, the pendulum would return to the center. What happens if we have an off center motor that tends to make the rocket yaw counter clockwise (to the left)? The forces that make the rocket turn about it's center of gravity are not directly applied to the pendulum so it will lag behind (as seen from outside) and from inside the pendulum will be seen to be deflecting to the left, same as above. Oops, the above system will tend to make the rocket turn more to the left...positive feedback...Loop...Crash! Bad idea. Reversing the connection between the pendulum and fins would make it tend to react properly to yaw but make the rocket turn downwind in a gust. Not good.

Plan B. Suppose we put a pendulum ahead of the center of gravity. In the above cross wind it will try to steer the rocket to the left and as the rocket starts to turn the nose will be accelerated to the left and center the pendulum. It seems likely that the net reaction will be minimal. Now, if the rocket starts to yaw counter clockwise (accelerating the pivot to the left) this time the pendulum will swing to the right (as seen from inside the rocket) and tend to steer the rocket to the right (clockwise). Hmmm, just what we want. We should note that the distance between the center of gravity and the pendulum will determine the relative magnitude of the reaction to lateral accelerations and yaw accelerations.

Ok, so far it looks like plan b might be possible. What happens when the motor burns out? Oops, now the primary force on the rocket is drag and not thrust. A weight on the end of a stick style pendulum will want to flip over and make the rocket fly backwards. Bad idea.

Plan C. How about a weight that is free to move horizontally (with respect to the body tube)? Well, it would react just like the pendulum in plan B except it would not need to "flip over" at burnout. Doesn't sound too bad, does it?

Bottom line:

Will it work? I don't know, maybe it would. I certainly wouldn't argue that it couldn't work, particularly when you consider that model rocket guidance systems don't have to work very well or for very long. But is it really worth all that effort to build a system that works about the same as passive fins?

Can I use Gyroscopes to stablize my rocket without fins?

This one's going to need a little more ground school.

Gyros fascinate us because they violate our common sense perceptions of mass and force. Everyone who has played with a toy gyroscope marvels at how it "resists" the twisting and turning of your hand. Eventually, most rocket hobbiests come up with the idea that if you put a gyro on board a rocket then it would "resist" all of the external disturbing forces and cause the rocket to fly straight without any fins.

Sorry, it doesn't work that way.

Gyroscopes work on the principle of rotational inertia. Just like with linear inertia (where a mass moving along a line will continue along that line unless disturbed by an outside force) a mass set spinning on an axis will continue to spin around the same axis unless forced to change. If you do force it to change, however, the results are not what you'd expect.

The reason the passive gyro won't work is due to the physics of rotation. The basic gyro "law" is as follows. Gyroscopes have three axes: the spin axis, the input axis and the output axis; all at 90 deg to each other. Twisting the gyro about the input axis will cause a torque about the output axis. Putting this in rocketry coordinates, if the gyro rotor is spinning on the long (roll) axis of the rocket, then anything that causes a rotation about the yaw axis will torque the rocket in pitch and visa-versa. This means that if you launch your finless rocket with a gyro spinning vertically, then a gust of wind from the North will cause it to veer East or West (depending on which way the rotor is spinning).

"Well," some folks argue, "then all I have to do is put another gyro with its rotor spinning along the yaw axis and maybe a third spinning on the pitch

axis. That should 'resist' torque from any direction." Sorry again. Just as weathercocking is an example of linear vector addition, the angular momentum of spinning gyro rotors add up in the same manner. Three identical rotors placed orthogonally like that will cancel each other out (vectorially adding up to zero) and act as if they weren't even there (except that you'll be lifting a *lot* of useless mass :-).

The correct way to use gyroscopes in a guidance system is as a REFERENCE PLATFORM. What that mean? Well, remember how a spinning rotor will continue to spin on its initial axis unless disturbed by an outside force? Rather than lashing the gyro to your payload section and forcing it to twist with your rocket, it should be mounted in a gimbal (a two axis bearing originally invented to keep ships' lanterns vertical in heavy seas). In this way, no matter how much your rocket pitches and yaws, the rotor will continue to spin about the same axis it started with on the pad. With this constant "up" reference, you can build control systems to keep the rocket heading in that direction. There are several ways to do this:

Fins, Mechanical

This is probably the closest thing to the ideal passive gyro that everyone thinks of since it's all-mechanical. With a fairly massive gyro rotor spinning in a gimbal, bellcranks can be run from the gimbal axes down to the fin pivots. The only tricky parts are remembering to cross the belcrank rods to get the reversed action required (See "Rear Mounted Fins" above). Also, some means of providing recovery that doesn't blast the gyro and linkages with ejection gas is needed.

I've heard of such an all-mechanical design by word-of-mouth, but was unable to find any references in either **AmSpam/Sprocket** or **HPRM** (but my collection only goes back to late '91 for the former and mid '92 for the latter) so I decided to design my own. It uses RC airplane components for all the movable pieces (cheap and reliable) with a homebrew gyro and gimbal. It will be about the size and shape of a LOC Onyx, since that will give me a baseline comparison.

Fins, Electronic

The more sophisticated approach to gyro control is to use a "real" electronic control system combined with the reference platform. While I haven't found any reference to such a system actually being built, an excellent source to draw from would be the Zunofark design described above. If one were to replace the 4-direction Sun sensor with rotational position sensors on the gimbal axes (along with the appropriate signal conditioning), you would have a very workable setup. A setup, one might add, that could be programmed to head in any direction, not just towards an external signal source (can you say "Inertial Guidance"? I knew you could :-)

Historical note: This is exactly how the German V2 guidance system worked, the only differences were in the details: It had fixed rear fins for basic stability, trim tabs on the trailing edges of the fins, plus (since it had to travel outside the atmosphere) graphite vanes to vector the exhaust. While it didn't have modern digital electronics, it used very similar analog predecessors. Also, the gyro platform had a three axis gimbal so that roll was controlled as well as pitch and yaw.

The gyro platform was set up to keep the rocket absolutely vertical WRT its launch site. To hit a target, the launch pad was aligned with the rocket's pitch axis aimed towards the target. After liftoff, an actuator pushed on the pitch axis of the gyro forcing it off center. The guidance system interpreted this as an error and "corrected" it by pitching the rocket the other direction (towards the target). As the actuator continued to push, the rocket continued to pitch over until it ran out of fuel; at witch time it was (theoretically) directly over the target and heading straight down. Range was controlled simply by controlling the rate of the pitch actuator and how long into the flight the pitch program started.

Gimbaled Motor

The only example of hobby rocket guidance done the way the "big boys" do it, was covered (somewhat sketchily) in the May/June 1993 issue of **HPRM**.Richard Speck designed a gimbaled motor system consisting of a two axis gyro reference platform combined with a two axis motor gimbal. This was an all analog system which even included phase comparitor circuitry to prevent over correction. The first version of the test vehicle hedged its bets and included fins, but the second one had none; a true finless missile!

The design was used as a basis for an eight foot "high fidelity" Saturn V model with five engines in the first stage; the central one being fixed and the outer four each being on a one axis gimbal along the pitch and yaw axes, just like the real thing! A "progress report" photo appeared in the Sept/ Oct 1993 issue of **HPRM**.

2nd Gyro torquing

Finally, there is a technique for controlling rocket attitude without fins, gimballed motors or any outher external affectations. In fact, it's very close to the presumed ideal of a gyro that "resists" external forces all by itself. The technique was originally used to stabilize ocean liners along their roll axis but is now used in some spacecraft to do attitude control without the use of gas jets.

The first thing you need is a reference platform to tell you which way is "up". This can be a small mechanical gyro with encoders on the gimbal axes like we've been discussing, or even a non-gyro system like horizon sensors (this is the way satellites do it) or a "target" sensor like sun guidance.

The second part is the control gyro. It must be fairly massive and positioned somewhere around the rocket's CG. Actuators are placed on the gimbal axes so that when the reference platform detects an error, say on the yaw axis, the

actuator twists the gyro's pitch axis which forces it to precess in yaw. If you've got the signs hooked up right, this will counter the disturbing yaw and put you back on track.

While the theory is good and has been proven out on real spacecraft (such as the "Magellan" Venus orbiter) it all seems quite involved for a hobby rocket. I'm sure someone out there will try it for just that reason :^)

14.2 All this talk about reference platforms seems so complicated. Why not get some of the gyros the RC-Helicopter folks use? These are small, relatively cheap, and are designed to hook into servos.

This comes up almost every time the conversation turns to gyro control. The main reason this type of gyro won't work is that it is a *rate* gyro. This means that it doesn't give you the absolute "up" reference like a position gyro, but rather just how fast you're turning about an axis.

This is not to say that a rate gyro can't be used in a guidance system. It's done all the time in professional rockets, but the sophistication necessary to integrate the rate signal to get a position is beyond the capabilities of most hobbiests.

Jon Dunbar (jdunbar@slee01.srl.ford.com) had some further input: "I was talking with Rob Rau of High Technology Flight about this. The reasons why R/C helo gyros will not do for rockets are as follows: the accelerations are so drastic that RCG (r/c gyros) cannot react fast enough. Also, the sampling rate is also too slow, and are only good for about 5 degrees of deflection from whatever normal reference point is set up. We all know that rockets get far beyond that 5 degree limit. I suggest that if you want a system that will work with rockets, contact Bob Rau at HTF. [*See the address section for his address and phone - JH*] Call him up and get one of his catalogs...you will be impressed!"

To that, however, Metm Kallend (METMKALLEND@minna.acc.iit.edu) counters: "It is true that heli gyros are rate gyros and will not hold an absolute heading. HOWEVER, they are still useful for damping undesirable deflections (which is why we use them in tail rotor circuit). I have seen many launches where a rocket clears the launch rod, then turns 20-30 degrees in random direction. This is the sort of thing that a rate gyro could handle. Incidentally, my heli will yaw (at full right control) at about 1000 deg/sec (3 rps) without causing a problem for the gyro. I don't think the pitch rate in a rocket will give a problem to these gyros! Also handles linear accelerations very well, and costs < $100 by quite a bit."

14.3 What are some of the sources for stabilization equipment?

If you don't want to "roll your own" WRT delicate hardware like gyroscopes, etc., there are places that sell such things that are suitable for hobby rocketry, or at least the HPR end of it.

The Japanese company muRata (that's the way they spell it on their literature) makes a very compact, piezoelectric solid state rate gyro that measures only 25 x 25 x 58mm and weighs only 45g. It is extremely resistant to temperature, shock and noise. The down side is that it runs $200 and that's for only one axis! If you're still interested, contact:

muRata Erie North America
2200 Lake Park Drive
Smyrna, GA 30080
(800) 831-9173

Robert Kinder (rkinder@inca.gate.net) reports on some sources that he's found: "In reference to the many recent discussions about the hand made gyro published in **HPR** magazine and the pendulum guidance systems, here's what appears to be an excellent source of guidance components small enough for HPR projects:

Humphrey Inc., Dept. CA391
9212 Balboa Ave.
San Diego, CA 92123
Ph. (619) 565-6631, Fax (619) 565-6873

Humphrey manufactures a full line of guidance system components for use in rockets, missiles, target drones, etc. Their product line includes: "gyroscopes, vertical indicators, north seekers, rate sensors, position transducers, accelerometers, pendulums, magnetometers, directional surveyor systems"

As an example, they offer a 2.3 inch diameter by 3.25 inch long 2 axis spring driven gyro. It operating time is 60 seconds, minimum, which should give you plenty of time up to burnout. This gyro is shock proof up to 85 gees, 10 msec (all axes) and weighs 345 grams. It's output is via potentiometer pickups.

Using this 2-axis gyro would have solved much of the difficulty encountered by the hand made gyro team in the above referenced HPR magazine article. Note that this will probably be *real* expensive -- all military spec. stuff.

A cheap gyro supplier that may be more suitable for HPR low-budget projects is:

Gyration, Inc.
Saratoga, Calf.
(408) 255-3016

Gyration makes small and inexpensive (about $500.00) gimballed and single axis gyros. I have no direct information this."

While on the subject of cheap precision parts, we have an enthusiastic report from Mark Spiegl (spiegl@rtsg.mot.com): "American Science and Surplus in Chicago is very possibly the most awesome store on Earth. Where else can you get WW2 aircraft gyros, 3'x3' fresnel lens, a Tesla coil, the guidance system to a heat seeking missile, and countless other bizarre goodies. They have a 70 page newspaper print catalog, which is revised every month. I think they will send one free just for asking. American Science also runs two store fronts. One is located in Chicago proper and the other is in the western suburb of Genevia."

The address for mail order is:
American Science & Surplus
3605 Howard Street
Skokie IL 60076
(708) 982-0870

14.4 What can you tell me about control systems for rockets?

Every rocket has a control system. Unlike Guidance Systems, which affects the flight path of the rocket, a Control System determines when the various flight events take place. For a simple model or HPR Lite rocket, the control system is built into the motor. After ignition, the only flight event to be controlled is the recovery system activation, so the "control system" consists of the delay and ejection charges in the motor.

Moving up one notch in sophistication, a simple system for controlling remote staging is the well know mercury switch/flash bulb combination. At lower stage burnout, the blob of mercury flys forward against the contacts completing the firing circuit for the upper stage. The upper stage ignitor is usually a flashbulb or sometimes an electric match. Power comes from either a small "button" battery or a capacitor charged up just before launch.

But what if you have lots of events to control? Say for some very high flying HPR rocket you don't want the parachute to eject at apogee since a parachute opening at 20,000 feet could drift for miles. OTOH, you don't want the rocket to build up too much speed falling back down to a reasonable altitude. You should eject a drogue 'chute near apogee then the main 'chute at, say, 500 feet above the ground. Tricky.

To achieve this, you need devices called sequencers, which come in many forms, plus remote activation charges and other devices. Sequencers come in several basic forms:

Timer

If you are fairly comfortable with the projected flight profile of your rocket, timers are a relatively inexpensive way to control the flight. The timer is started by some sort of signal on the pad. Sometimes this can be the ignition signal, but more often it's some sort of "first motion" detector which can be a microswitch that senses the launch rod or a fine wire that is broken as the rocket leaves the pad. As the flight progresses the timer executes the various functions such as staging, switching on a payload, firing the ejection charge(s).

The down side of timers is that they are "open loop." This is engineering term which means that they work independently of the events surrounding them. If, for example, you get a motor that burns a little "hot" the amount of coast time you programmed into the timer might not be sufficient and the rocket might still be traveling at a high rate when it fires the ejection charge. You can partially "close the loop" by having the timer be started by a flight event (e.g. a recovery timer started by an inertia switch at burnout) but you are still stuck with the pre set timing values.

Altimeter

Altimeters can be both a payload and a control system. The simple ones only record and playback altitude information. These are described in the "Payloads" section 5.2.2.3. The more sophisticated ones can actually control events based on the rocket's altitude. This can be more effective than timers since it's fully "closed loop," i.e. it operate's based on information coming from actual flight events rather than a rigid timed sequence.

As an example, you could program the altimeter to turn on a payload at a certain altitude on the way up, note the maximum altitude and fire the drouge ejection when the rocket had fallen back 100 feet (to make sure it had enough velocity to deploy the 'chute). Finally, you could have the main 'chute deploy when the rocket was back down to 500 feet above the pad altitude; plenty of time to have the main 'chute deploy but not drift too far.

Radio Control

There's no substitute for the Mark I eyeball :-) R/C controllers allow an operator on the ground to execute flight events based on observations of how the flight is progressing. The most common use for this is as a backup recovery system activator. If the standard recovery system doesn't deploy when you expect it to, you can hit the button yourself. Some folks even use this for the primary recovery activation. While it sounds good in theory to have this kind of ground control over your rocket (very James Bond-like) it takes nerves of steel to allow it to fall and resist the temptation of "punching out" early.

An R/C system is relatively simple consisting of a receiver and an actuator of some sort. This actuator can be either a mechanical servo to physically activate a recovery system or perform other functions, or an electrical signal initiator (such as used with the timers and altimeters) to fire pyrotechnics. The ground based transmitter completes the system.

14.5 What are some sources for electronic control systems and components?

Adept Rocketry

Adept has probably the widest selection and best developed line of hobby rocketry controllers available. They have both altimeter and timer based controllers in addition to payload style altimeters.

Countdown Hobbies

Countdown is not a manufacturer, but is probably the most varied retailer of hobby rocketry supplies. You can find everything listed in this section and, as they say, much, much more!

Designex Corp

Bill Schaffer has just introduced a small (2" x 4") timer with a range of 3 to 60 seconds.

Pratt Hobbies

Doug Pratt has recently introduced his ECS-2 radio controlled recovery system. Intended primarily as a backup, it can also be used for primary recovery. The advertised range is 5,000 ft and it will fit in body tubes 2" dia and up.

Robby's Rockets

Robby's doesn't make control systems, but they are one of the largest suppliers of the secondary items needed to make them work; specifically flashbulb ignitors, thermalite and stand-alone ejection charges.

John Sicker

John (jws@halfog.asrc.albany.edu) makes and sells the QDST crystal controled, 4 channel timer which fits in a 29mm tube. The timer was flown on a "P" powered flight at LDRS and worked perfectly. Previously sold through MicroBrick (now MRED).

Transolve Corp.

While concentrating mostly on payload style altimeters, their high end models have expansion ports which allow integration into other control systems.

14.6 I keep launching my rockets completely out of sight! Are there any kinds of Recovery Aids to get them back?

Tracking Powder

The simplist and cheapest (although messiest) way to help spot your bird is to use tracking powder. The most commonly used materials are carpenters' chalk (available at building supply and large hardware stores) and tempura paint (available at art supply outlets). The use of tracking powder is required for all NAR altitude events.

The concept behind tracking powder is simple. At ejection the charge pushes out the powder along with the recovery device where it disperses into a large cloud that is much more visible from the ground than your tiny rocket. Of course the same turbulence that disperses the powder also smears it all over the body tube and fins, but it's a small price to pay for getting your model back!

The most popular colors, because they seem to be the most visible under the greatest variety of conditions, are bright red, orange and pink. You might think of just using an extra large slug of the talc you're already using to keep the chute from sticking, but white is only really visible in a dark blue sky (polarized sunglasses help a lot) and most skys have some degree of haze, high clouds or smog to lighten them to the point where white is useless. Dark colors don't do so well under most conditions. Blue is out, for obvious reasons, but black could be used on an overcast day or against a smog brightened sky. OTOH, red works pretty well against overcast and there's no need to carry a bunch of different colors in your range kit.

The amount of powder to use varies by the application. A typical model rocket, like an Estes Commanche III, might only need an ounce or two to make a cloud visible from it's 2,000 foot max altitude, but HPR birds going for altitude records at 25,000 feet or more can use several pounds! Some flyers just pour the stuff down over the recovery system just before popping the nose cone on. Others, trying to hold down on the mess, wrap the powder in little pouches of recovery wadding or some such in the hope that it will be blown free before releasing the messy cloud. The risk here, of course, is that the pouch might not open at all if there isn't enough turbulence (say, if it's ejected right at apogee). Some even use the parachute itself as the pouch, in a sort of compromise.

Sounders

The next step up in sophistication is an audio sounder which usually some sort of piezoelectric device which puts out an incredibly shrill, piercing tone at the upper end of the human hearing range. This is chosen because 1) the higher frequency carries farther, and 2) it's not likely to be confused with any other background sound.

A simple beeper can easily be designed and assembled from materials found at any electronic hobbiest store (e.g. Radio Shack) and some may even have kits available that are easily adaptable. Those that want a purpose designed device, however, still have several to choose from. Estes has the "Transroc II" which is a combination of a sounder (sized to fit in BT-20)

and hand held directional microphone/amplifier with a narrow-pass audio filter. Note: this item has been dropped from the current catalog, although some should be available in hobby stores and other outlets for a while yet.

Going up the scale in size and volume, Adept has a beeper for 1.5" and larger body tubes which is available in either kit or pre-assembled form. And finally, for the truly impatient, LOC/Precision sells a "snap 'n go" beeper that's completely pre-assembled and designed to attach to the back of a nose cone or recovery lanyard. It will fit in their 2.14" and larger airframe tubing.

Transmitters and Homing Beacons

This is the top of the line for sophistication in getting your rocket back. If you check back in Transmitter Payloads Section, you'll see that many data transmitters also have a simple "beacon" mode for helping locate your bird with the aid of a directional antenna. To date there's only been one manufacturer who's come up with a highly optimized system for rocket location; and even at that, it's an adaptation of one used in the R/C airplane hobby successfully for years.

Built by Walston Retrieval Systems, it features a 20 mile air range, 2 mile ground range, 4 gram launch weight (including battery) and a 3 element directional antenna on the ground receiver. This specialization doesn't come cheap, though, as these systems are in the $200 range. Still, if you are going to sink a Kilobuck into that altitude record bird, it's nice to be able to find it later!

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